



A First Principle Look at the Electromotive Force Generation from Molybdenum and Niobium Alloys

June 2021

Changing the World's Energy Future

Richard S Skifton



INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

DISCLAIMER

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

A First Principle Look at the Electromotive Force Generation from Molybdenum and Niobium Alloys

Richard S Skifton

June 2021

**Idaho National Laboratory
Idaho Falls, Idaho 83415**

<http://www.inl.gov>

**Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517**

15 June 2021

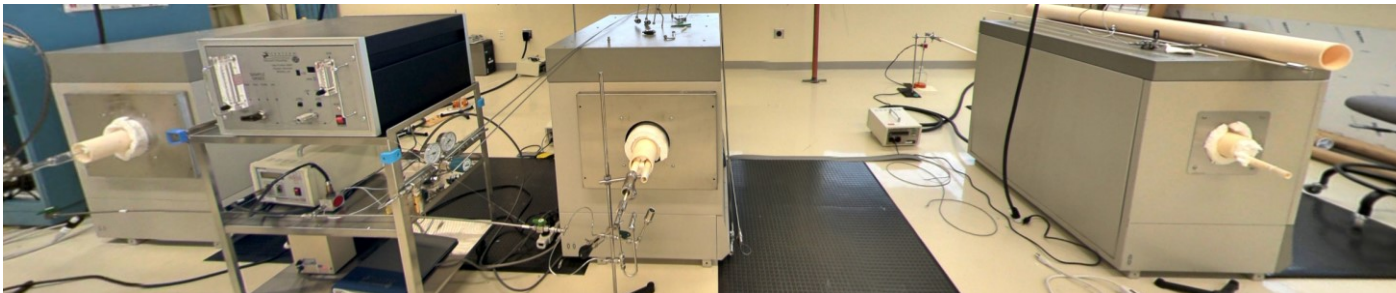
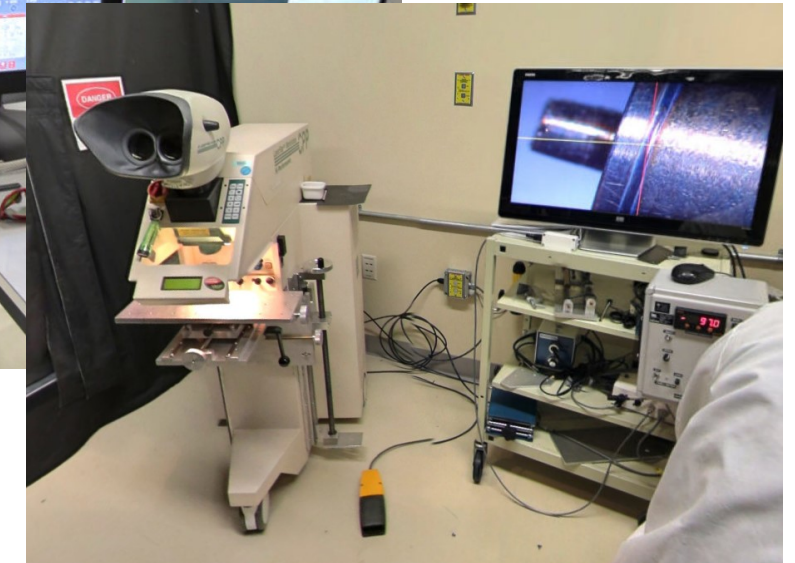
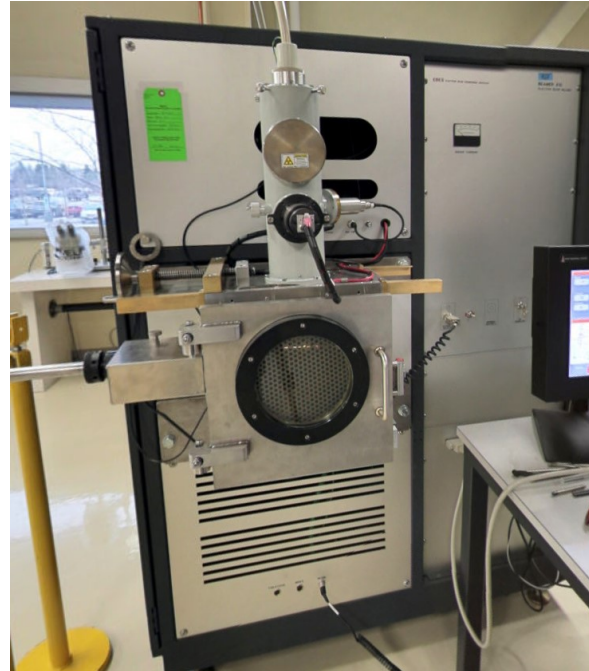
Richard Skifton

Nuclear Instrumentation Engineer

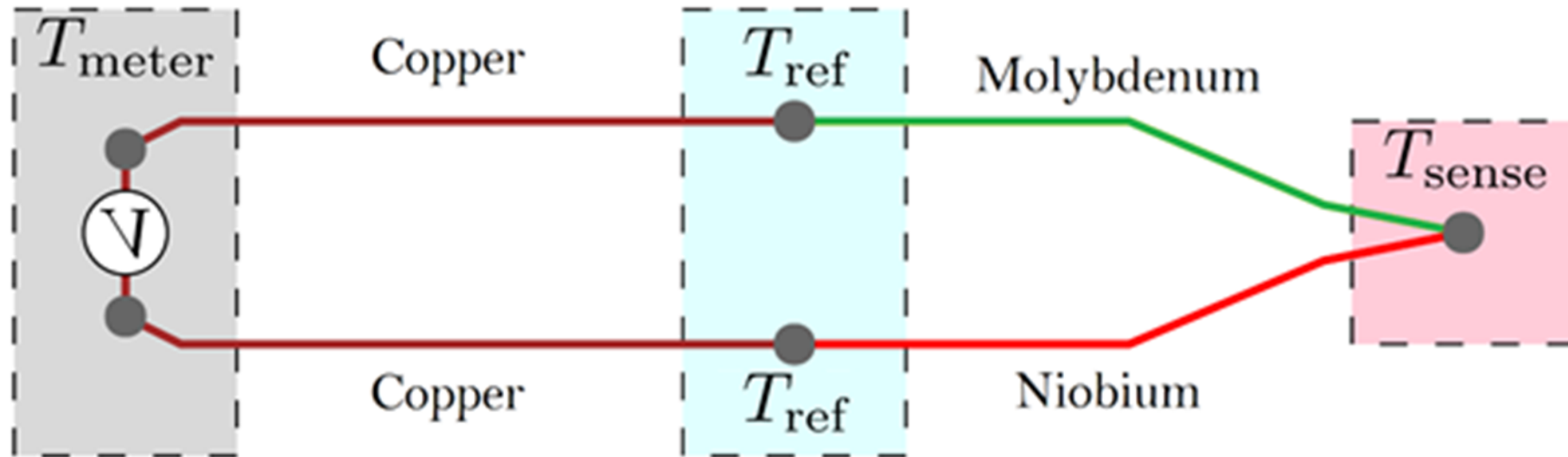
A First Principle Look at the Electromotive Force Generation from Molybdenum and Niobium Alloys

Measurement Science Laboratory

- <https://inl.gov/360-tour/high-temperature-test-laboratory>



The Electromotive Force (EMF)



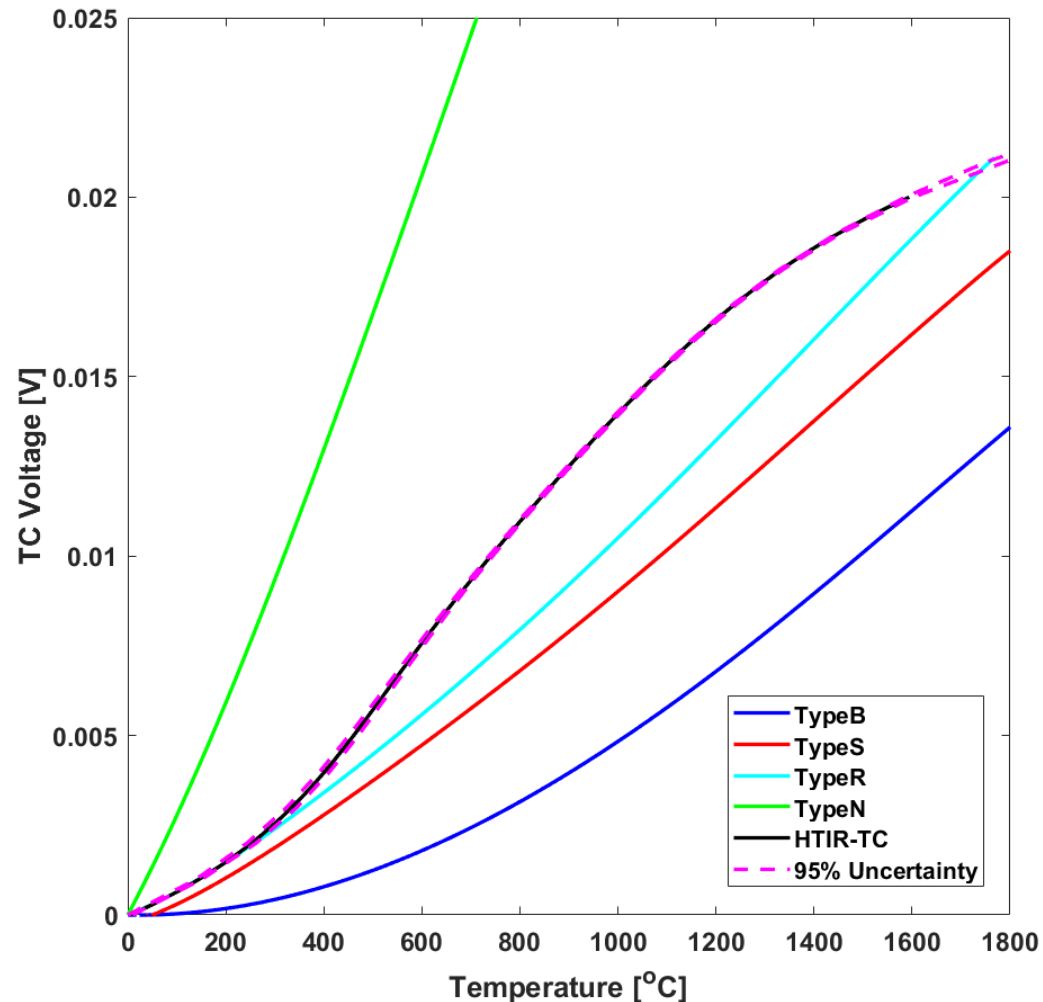
EMF generated along the length of cable:

$$EMF = \int_0^L S_1 \frac{dT}{dx} dx - \int_0^L S_2 \frac{dT}{dx} dx$$

EMF generated along the temperature gradient (assuming homogeneous wires):

$$EMF = \int_{T_L}^{T_H} (S_1 - S_2) dT$$

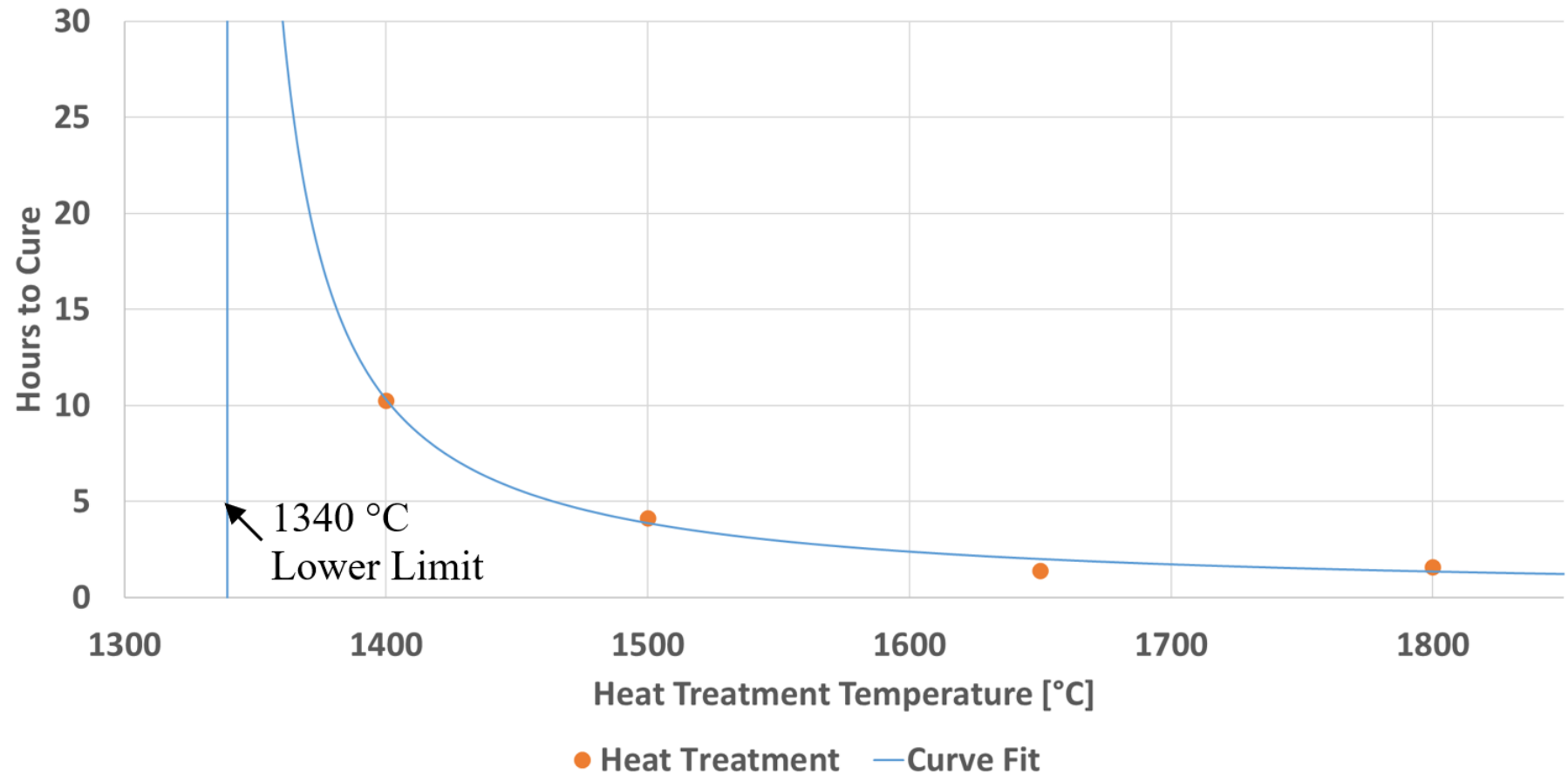
The Temperature Calibration



- Calibration fit using both low and high temperature ranges
- 5th order polynomial works best
- Comparable output to other commercially available TCs
- Linear region between 700 °C and 1500 °C

Avoiding Heterogeneous Cables...

- Heat treatment necessary for stable calibration
- Time and temperature dependent with a 1/x law
- Must reach higher than ~1340 °C to take effect
- Minimum timeframe at around 2.5 hours

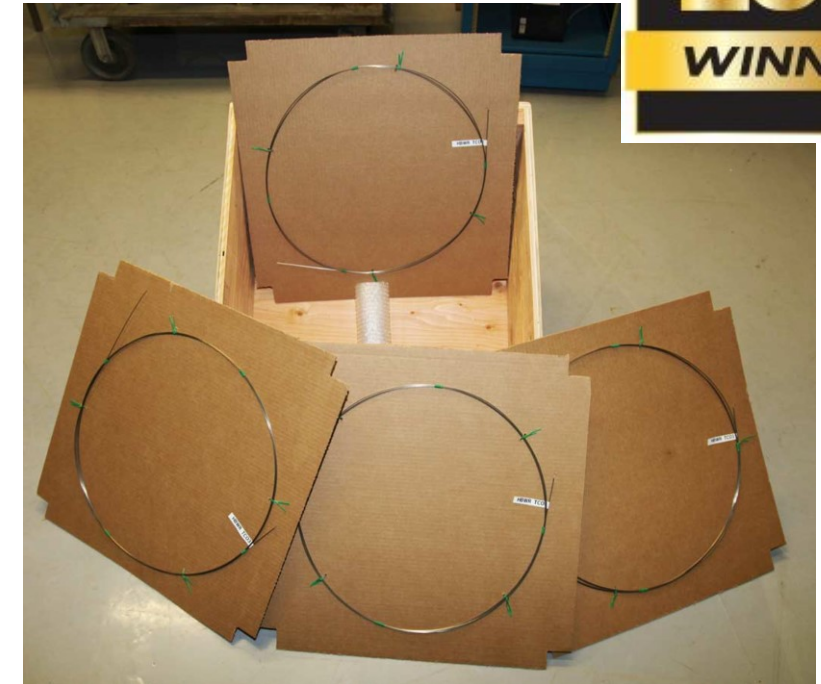


$$EMF = \int_0^L S_1 \frac{dT}{dx} dx - \int_0^L S_2 \frac{dT}{dx} dx \quad \longrightarrow \quad EMF = \int_{T_L}^{T_H} (S_1 - S_2) dT$$

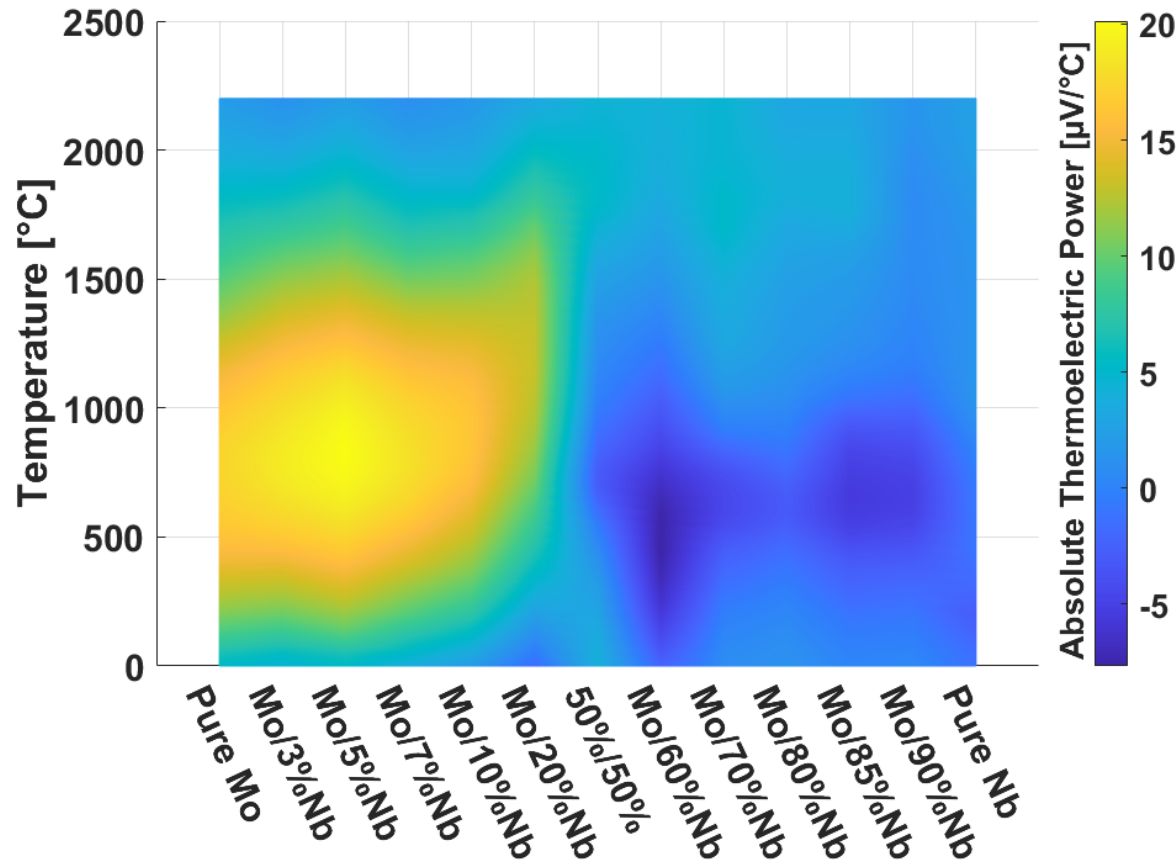
The High Temperature Irradiation Resistant Thermocouple

Table 1: Summary of performance parameters for the HTIR-TC

Performance Parameter	Performance Requirement Fuel Test Application	Performance Requirement Stand-Alone Application
Temperature Range	Room Temperature - 1600°C	Room Temperature - 1600°C
Accuracy	Not Specified	±1%
Drift	-3% for 4.5×10^{21} nvt (thermal)	-3% for 4.5×10^{21} nvt (thermal)
Life	4.5×10^{21} nvt (thermal), or 10 thermal shocks (room temperature to 1600°C)	18 months or 4.5×10^{21} nvt (thermal)
Mechanical Ruggedness:		
Rugged Junction	Rugged mechanical junction design	Rugged mechanical junction design
Bend Radius	Minimum of 2 feet	Minimum of 2 feet
Thermal Shock	5 sudden startups and 5 sudden shutdowns—each causing a thermal shock on the order of room temperature up to 1600°C	100°C/hr
Response Time	<0.5 seconds	<0.5 seconds



EMF from Molybdenum/Niobium Alloys

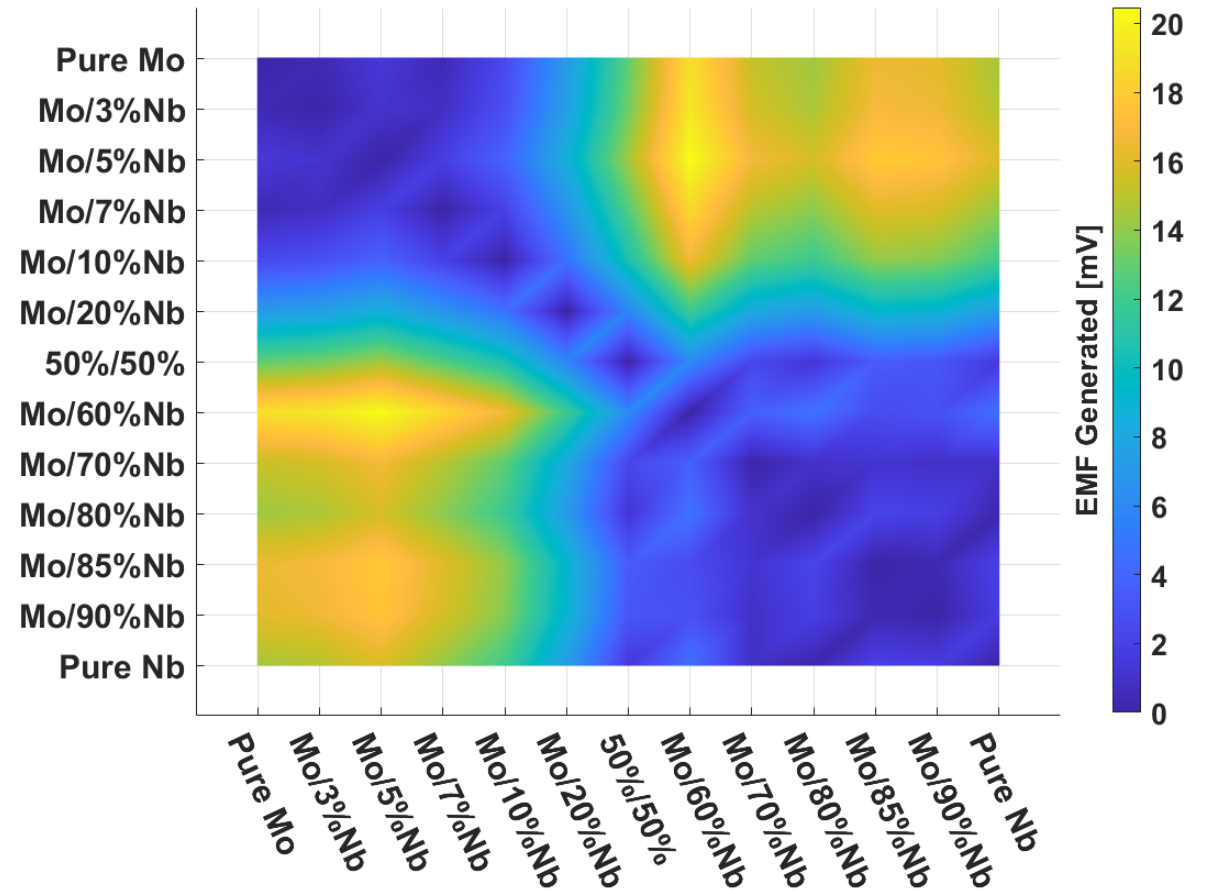


- Data raised from R. Schley, G. Metauer, “Thermocouples for Measurements Under Conditions of High Temperature and Nuclear Radiation,” in Temperature: Its Measurement and Control in Science and Industry. **5**, Part 2, J. F. Schooley, ed., American Institute of Physics, New York, NY, pp. 1109-1113, (1982)
- EMF from temperature gradient, ΔT , shown between 0 and 2200 °C.

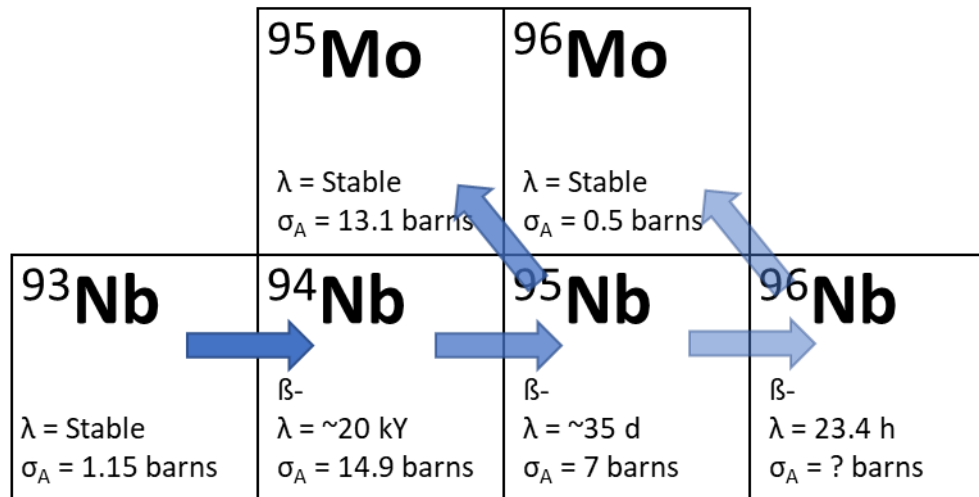
$$EMF = \int_0^L S_1 \frac{dT}{dx} dx - \int_0^L S_2 \frac{dT}{dx} dx \quad \longrightarrow \quad EMF = \int_{T_L}^{T_H} (S_1 - S_2) dT$$

Thermocouples from Mo/Nb Alloys

- Temperature gradient, ΔT , held constant between 0 °C and 1600 °C
- Symmetrical about the diagonal axis
- Greatest coupling with Mo/5%Nb vs. Mo/60%Nb
- Could be further incremented via advanced manufacturing methods



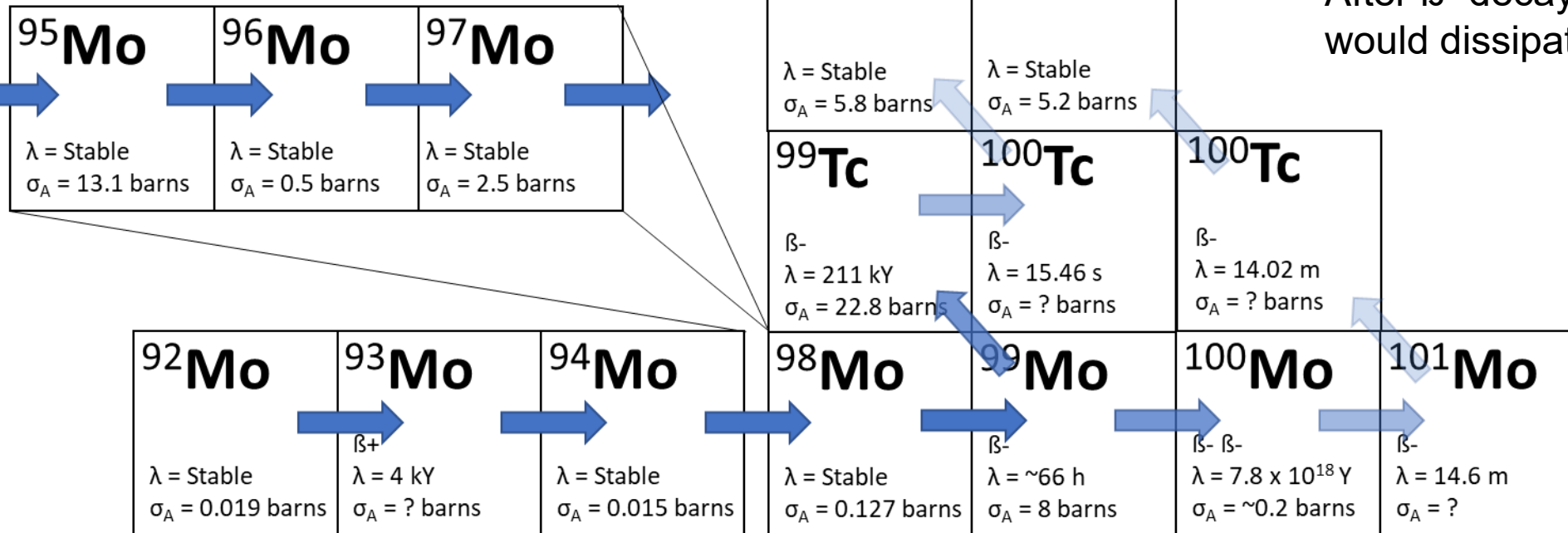
The Path of Transmutation for Niobium (Nb)



- Niobium begins with 100% stable ^{93}Nb
- After neutron bombardment niobium has the potential of transmuting through β^- decay
- After β^- decay, this begins the long process of stable Mo isotopes

The Path of Transmutation for Molybdenum (Mo)

- Molybdenum has various stable isotopes to being with.
- After neutron bombardment molybdenum has the potential of transmuting through β^- decay
- After β^- decay, the transmutation would dissipate to stable ruthenium



Conclusion

- HTIR-TC is a long-lasting nuclear TC up to temperatures of 1600°C
- Alloying Moly/Nb would increase EMF signal
- Alloying Moly/Nb may increase lifetime of TC thermoelements through controlled transmutations



Questions?

Richard Skifton

Idaho National Laboratory

Richard.Skifton@inl.gov

1 (208) 526-2696